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Some Factors Influencing the Life and Performance Reliability of High-Precision Potentiometers

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ABSTRACT

At the request of the Bureau of Naval Weapons, this Laboratory undertook a study of various factors which govern the useful life of high-precision potentiometers. Emphasis was placed on the determination of the relationship between lubrication, wear, potentiometer life, and operating characteristics, with particular attention paid to the generation of electrical noise. The study was c o n d u c t e d on a number of linear precision potentiometers of the type used in Navy computer systems which had been subjected to life testing by a·Navy contractor. One manufacturer had used oil as the contact-arm and winding lubricant; the other three used greases. Most of the wear was concentrated on contact arms and was most severe where oil had been used as the lubricant. Potentiometers made with precious-metal windings exhibited the least wear. Both oil and grease, usually in very small amounts, had been used for lubricating the potentiometer b a l l bearings. About half the bearings were rough in operation, and two had become locked because of wear and fretting corrosion products. Size of the contact-arm-wear scars showed no simple correlation with change in total resistance or torque required to operate the potentiometers. Where wear scars were large, increasing wear coincided with increase in departure from linearity. Though noise levels of all potentiometers rose during the life tests, those with contact arms having the greatest wear at the conclusion of the tests tended to produce the least noise. It was evident that increase in noise during service is related to loss of contact arm lubricant by evaporation, creep, or migration. This leads to the generation and deposit of wear products and poorly conducting films between contact surfaces. Replenishing the lubricant reduces the noise. The use of low-volatility lubricants in conjunction with a nonwettable fluorochemical barrier to prevent creeping of the oil from vital a r e a s is recommended. More liberal application of l u b r i c a n t to the ball bearings permitted by the use of barrier films to prevent oil migration should provide longer bearing life.

PROBLEM STATUS

This is a final report on this phase of the problem; work on other phases is continuing.

AUTHORIZATION

SOME FACTORS INFLUENCING
THE LIFE AND PERFORMANCE RELIABILITY OF
HIGH-PRECISION POTENTIOMETERS

INTRODUCTION

This report summarizes the results of a study by Naval Research Laboratory personnel of fifteen linear-precision potentiometers, subject of the "Engineering Final Report for Potentiometer Study," Contract No. N 164-10001, submitted to the Bureau of Naval Weapons by the Ford Instrument Company (1). The potentiometers had been subjected to a life test during which periodic measurements were made of total resistance, electrical noise, linearity, and torque. The purpose of the life test was to determine if new potentiometers were available which possessed longer life than those presently used in Navy computers manufactured by the Ford Instrument Company. Results indicated that the life of these new potentiometers exceeded the normal 50,000-cycle life expectancy.

The potentiometers were examined by this Laboratory at the request of the Bureau of Naval Weapons to determine if any relationship exists between lubrication, wear, potentiometer life, and operating characteristics, with particular attention paid to the generation of electrical noise. The introduction of noise by faulty potentiometers has become a major source of trouble in computer systems. Since the torque required to drive potentiometers in such systems is of importance, the condition of the ball bearings and lubricants was also examined.

DESIGN CHARACTERISTICS OF THE POTENTIOMETERS STUDIED

The potentiometers, products of four manufacturers, were supplied to this Laboratory by the Ford Instrument Company. Five types of construction were represented by three potentiometers of each type. They were 10,000-ohm single-turn sections of multisection potentiometers used in Navy computers (Drawing No. 1277404 (BuWeps)). They had been subjected to a 2,000,000-cycle life test under a load of 12 volts ac at 400 cycles per second. The contact arms were rotated at 30 revolutions per minute.

The manufacturers and the type of materials used in the construction of the potentiometers as outlined in the Ford report (1) are given in Table 1. However, no information was made available regarding the composition of the contact-arm materials or of the lubricants used on either the contact-arm windings or in the ball bearings.

EXAMINATION OF POTENTIOMETERS

The fifteen potentiometers were disassembled and the parts examined under 20 to 40 power magnification. The resistance windings of all the potentiometers were in the form of close-wound torroidal coils. The contact arms of the Source 2 units operated against one side of the torroid. Those in all the other potentiometers contacted the inside circumference of the torroid.

The collector brushes which operated against slip rings to provide a continuous electrical connection with the contact arms were in the form of wires in all potentiometers except those made by Source 2. The brushes in these units were in the form of flat single-leaf springs.

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Table 1
Potentiometers Studied

Designation	NRL Designation	Construction Designation
Source 1	1A	Precious-metal winding
Source 1	1B	Precious-metal winding
Source 1	1C	Precious-metal winding
Source 1	1D	Improved-process manufacture
Source 1	1E	Improved-process manufacture
Source 1	1F	Improved-process manufacture
Source 2*	2A	Improved-process winding
Source 2*	2B	Improved-process winding
Source 2*	2C	Improved-process winding
Source 3	3A	Improved design
Source 3	3B	Improved design
Source 3	3C	Improved design
Source 4	4A	Dwg. No. 1277404(67-307)
Source 4	4B	Dwg. No. 1277404(67-307)
Source 4	4C	Dwg. No. 1277404(67-307)

*The Source 2 potentiometers were smaller in size than
the others and did not meet the linearity requirements.
They were accepted by the Ford Instrument Company
as suitable for use in the life tests.

The general condition of each potentiometer was noted, particularly with respect to
the presence of debris or contamination, degree of contact-arm and winding wear, collector-
brush and slip-ring wear, type of lubricant, the condition of the bearings, and the nature of
the bearing lubricant.

The Source 2 potentiometers were particularly dirty; the debris appeared to consist
of wear products and oxidized lubricants. In some potentiometers fretting corrosion
products from the bearings had migrated on to the resistance windings.

Wear

Wear on the collector brushes was not severe, except for those in the Source 4 units.
These had worn 1/4 to 1/2 way through, and there was much evidence of wear particles
in the area. Slip-ring wear did not appear to be serious, though the surfaces appeared to
be rough in many cases, apparently from the time of manufacture.

As might be expected, the contact arms (or wipers) had sustained the most wear,
while the wear on the windings, since it was distributed over a much larger area, was
not severe in most instances. It was noted that the wear scars on the wipers were, in
general, in the form of ellipses and that the cylindrical configurations of the contact ends
of the wipers were similar in size and shape. The length and width of the scars were
measured with a Bausch and Lomb Zoom Macroscope and the areas of the scars computed
as though the surfaces were flat. This does not result in an absolute measure of the wear
scar area, but it is believed to be a relative measure of the amount of wear and the num-
ber obtained is more useful than a qualitative evaluation.

The wiper wear scar areas varied from 0.79×10^{-4} square inches to 6.36×10^{-4} square inches. Photomicrographs typical of these extremes are shown in Fig. 1 (Source 1, 1A) and Fig. 2 (Source 4, 4A). The average contact-arm or wiper wear scar area for each type potentiometer examined is given in Table 2. It is seen that the Source 1 potentiometers with the precious-metal windings exhibited the least wear. It was these units which were rated superior in the life tests (1).

Because of the difficulty of making measurements of wear on the windings, only qualitative evaluations were made. Wear varied from very slight to what has been designated as severe. It is notable that potentiometers which exhibited the most wear on the

Fig. 1 - Contact-arm-wear scar after 2,000,000 cycles of operation of Source 1, 1A potentiometer (darkened portion of scale represents 0.050 in.)

Fig. 2 - Contact-arm-wear scar after 2,000,000 cycles of operation of Source 4, 4A potentiometer (darkened portion of scale represents 0.050 in.)

Table 2
Average Contact-Arm Wear for Each Type Potentiometer Studied

Potentiometer Designation	Average Wear (square inches $\times$ 10⁴)
Source 1 (Precious-metal winding)	1.17
Source 3 (Improved design)	1.24
Source 2 (Improved-process winding)	1.56
Source 1 (Improved-process manufacture)	2.36
Source 4 (Dwg. No. 1277404(67-307))	5.45

windings were not necessarily those which had the most contact-arm wear. The amount of wear sustained by each potentiometer and the condition of the lubricants and of the ball bearings are outlined in Table 3.

Lubrication of Contact Surfaces

Oil had apparently been used to lubricate the wipers and windings of the Source 4 potentiometers, while greases had been used by the other manufacturers. An amber-colored grease had been used on the Source 1 potentiometers with the precious-metal windings (1A, 1B, 1C). A blue grease, possibly containing copper phthalocyanine, had been used in the Source 1 improved-process series (1D, 1E, 1F). The lubricants in the Source 2 and Source 3 potentiometers had solidified and in some instances had been reduced to a powder. They apparently had been greases originally. Some of the debris found in these units probably originated from the solidified lubricants.

The collector rings and brushes appeared to have been lubricated with greases. In some cases they may have been the same as those used on the wipers and windings. For instance the Source 1 (1D, 1E, 1F) wipers were lubricated with blue grease, but the collector rings and brushes in only the 1E appeared to have blue grease on them. Those in the other two potentiometers were lubricated with amber-colored grease.

Bearings and Bearing Lubricants

The conditions of the ball bearings ranged from those in the Source 4 potentiometers which operated smoothly and were bright, clean, and covered with an oil film, to those found in the Source 1 (1F) and Source 3 (3B and 3C) units, which were very rough, and in the latter units, partially locked. Some of the balls were covered with a rather dull brown film and showed evidence of having been scored, as may be seen in the photomicrograph of one of the Source 1 (1F) bearings in Fig. 3. All the bearings from these three poten-tiometers contained reddish-brown debris which can be seen both in Fig. 3 and in the photomicrograph of one of the source 3 (3B) bearings in Fig. 4. Approximately half the ball bearings in the fifteen potentiometers were rough in operation in varying degrees.

In most cases it was difficult to determine the nature of the ball bearing lubricants that had been used, particularly since the supply was usually quite limited. However, the presence of what appeared to be silicone gel in the bearings in the Source 2 potentiometers indicated that a silicone oil had been used as the lubricant. This condition has been noted many times where the silicones have been used as the lubricant for ball bearings and is but one of the several reasons why silicone fluids should not be used as a lubricant for ball bearings.

Table 3
Condition of Potentiometers Examined

Manufacturer	NRL No.	Contact-Arm Wear (sq. in. × 10⁴)	Resistance-Winding Wear	Contact-Arm Lubricant	Bearing Condition*	Bearing Lubricant
Source 1	1A	1.19	Slight	Amber-colored grease	Slightly rough; lubricant scarce	Apparently grease
Source 1	1B	1.54	Considerable	Amber-colored grease	Slightly rough; lubricant scarce	Apparently grease
Source 1	1C	0.79	Some	Amber-colored grease	Slightly rough; black debris	Apparently grease
Source 1	1D	2.36	Considerable	Blue grease	Fairly smooth; lubricant film	Apparently grease
Source 1	1E	2.04	Considerable	Blue grease	Smooth; lubricant film	Amber-colored grease
Source 1	1F	2.67	Considerable	Blue grease	Very rough; brown debris	Grease?
Source 2	2A	1.23	Very slight	Probably grease; dry, hardened	Smooth; silicone gel?	Silicone oil?
Source 2	2B	1.32	Very slight	Probably grease; dry hardened	Smooth; silicone gel?	Silicone oil?
Source 2	2C	2.12	Slight	Probably grease; dry, hardened	Fairly smooth; silicone gel?	Silicone oil?
Source 3	3A	0.82	Severe	Probably grease; dry, hardened	Slightly rough; bright	Apparently grease
Source 3	3B	1.48	Considerable	Probably grease; dry, hardened	Locked; brown debris	Oil?
Source 3	3C	1.41	Considerable	Probably grease; dry, hardened	Locked; brown debris	Possibly grease
Source 4†	4A	6.38	Considerable	Oil	Smooth, bright; wet with oil	Oil
Source 4	4B	4.78	Considerable	Oil	Smooth, bright; wet with oil	Oil
Source 4	4C	5.18	Considerable	Oil	Smooth, bright; wet with oil	Oil

* In general this refers to the worst conditions found in either one or both bearings.
† Source 4 units contained only one collector brush; all others contained two.
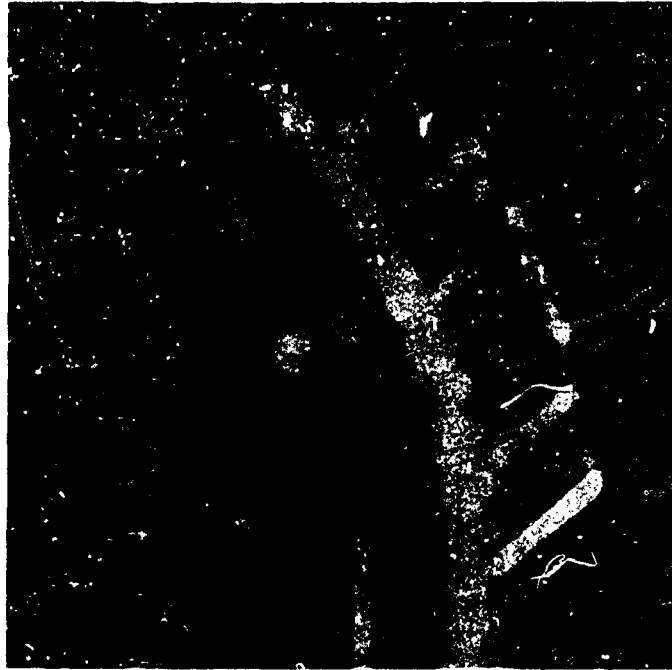
NAVAL RESEARCH LABORATORY

Fig. 3 - Ball bearing after 2,000,000 cycles of
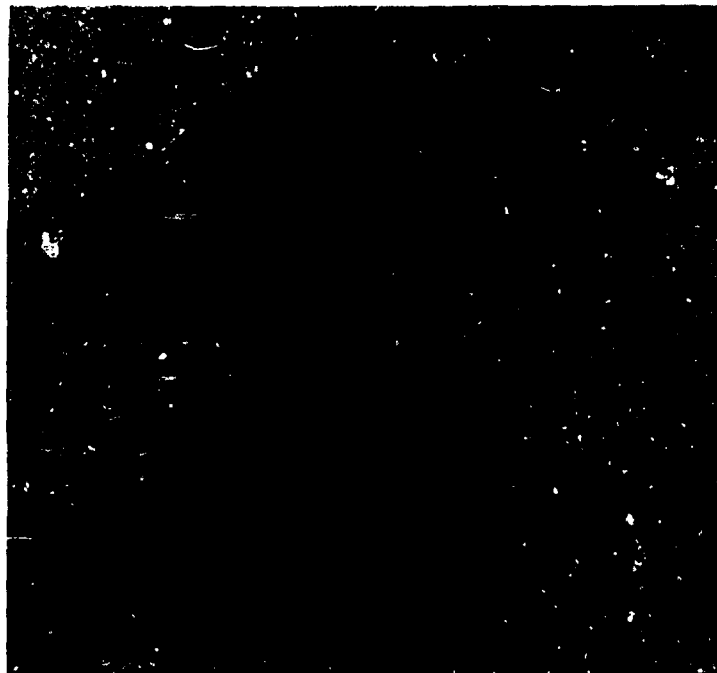operation of Source 1, 1F potentiometer

Fig. 4 - Ball bearing after 2,000,000 cycles of
operation of Source 3, 3B potentiometer

The reddish-brown deposits in the 1F, 3B, and 3C potentiometer bearings were primarily caused by fretting corrosion, either within the bearings or between the bearing bores and shafts. The bearings in the 3B and 3C units had been turning on the shafts on which they were mounted. This points up the need for more care in the fitting of bearings on shafts.

INTERPRETATION OF LIFE-TEST DATA

The total resistance, noise, linearity, and torque of the potentiometers were determined by the Ford Instrument Company at intervals of 200,000 cycles* of operation during the life tests. These data are tabulated in the Ford report (1).

The total resistance is defined as the resistance between the end terminals of the potentiometer with the contact arm positioned so as to give a maximum value (2). The value obtained is influenced by the nature of the wiper-winding contact, the condition of the collector-brush contact surfaces, and the resistance of most of the winding. Removal of metal from the windings by the action of the contact arm results in an increase in total resistance. However, if smearing occurs or if wear particles become embedded between the turns and cause shorting of the turns, a decrease in resistance will result (3). If the contact area on the wiper increases because of wear, any bridging or shorting of additional turns on the winding will also reduce the resistance. If the wear is so severe as to cause a reduction in contact arm force on the winding, a higher resistance reading may be obtained. The presence of nonconducting material (dirt, lubricant, etc.) between the wiper and winding may increase the resistance, and the value obtained may be greatly influenced by the voltage applied to the potentiometer. Finally, aging of the winding material can also cause a change in the total resistance. According to the Ford report (1), all but one potentiometer (Source 3 (3B)) stayed well within 2% of 10,000 ohms total resistance, although 5% deviation was permitted. The total resistance of the 3B potentiometer decreased by 45%.

From the foregoing, it is obvious that monitoring the change in total resistance during the course of a life test will not result in reliable information concerning winding wear. Examination of typical total resistance versus cycles of operation curves in Figs. 5 through 9 indicates that the total resistance usually tended to decrease as the tests progressed. This suggests that partial shorting of resistance coil turns by wear particles, bridging of additional turns, and lowering of contact resistance because of increased wiper wear area are the predominating factors.

Since resistance characteristics and deviation from linearity are related, many of the factors which influence total resistance are involved in the linearity characteristics of a potentiometer (4). Linearity is concerned with the deviation of the relationship of the actual electrical output and the mechanical input of a potentiometer from a straight line (2). The limit permitted in the Ford Instrument Company tests was 0.2%. The Source 2 potentiometers did not meet the linearity requirements as received but were considered acceptable for purposes of life testing (1). Only the Source 1 precious-metal-winding potentiometers (1A, 1B, 1C) still passed the linearity requirements by the time the life tests had ended.

Examination of typical linearity data in Figs. 5 through 9 shows that considerable scattering of the data exists. However, in most cases the deviation from linearity increased as the tests progressed and passed through a maximum near the end of the tests.

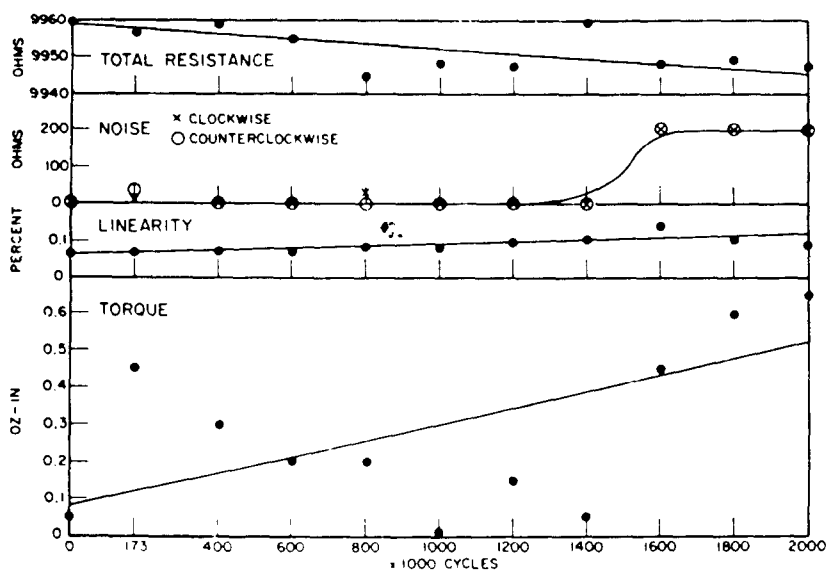* The first interval was 173,000 cycles.

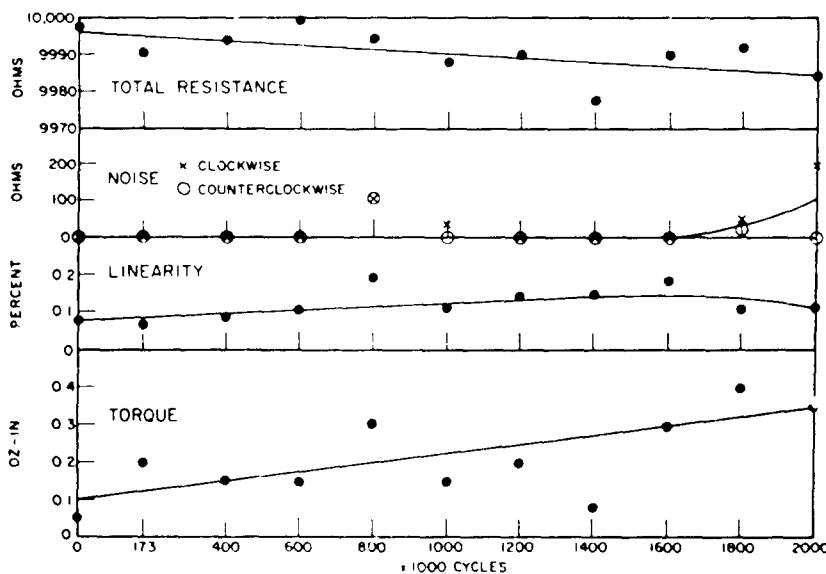Fig. 5 - Life test characteristics of Source 1, 1C potentiometer

Fig. 6 - Life test characteristics of Source 1, 1F potentiometer

The electrical or peak-noise resistance of a potentiometer is concerned with the generation of spurious electrical voltages when the contact arm is moved while a current is being carried through the contact arm to the winding. It is measured while the operating shaft (and contact arm) is being rotated, first in one direction and then the other, at 4 revolutions per minute while a 1 milliampere dc current is flowing through the contact arm and resistance winding (2). The maximum noise permitted in the Ford tests was 100 ohms.
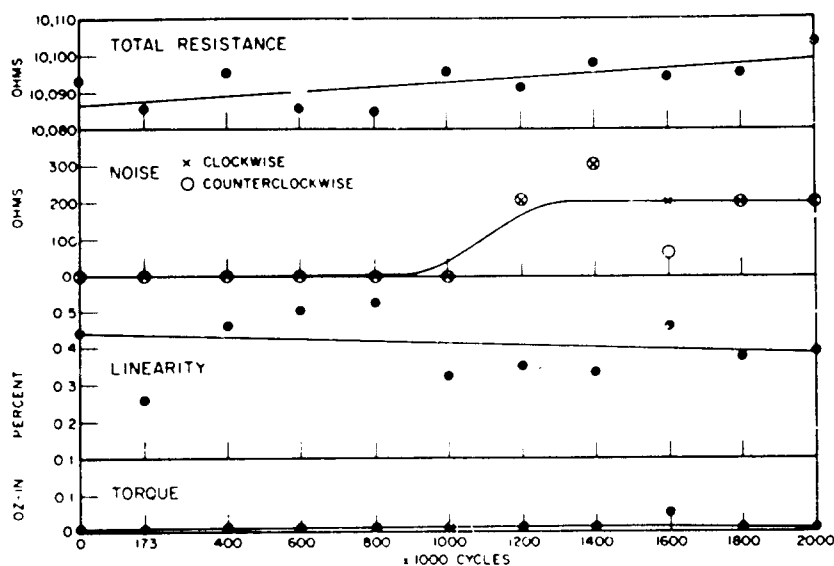
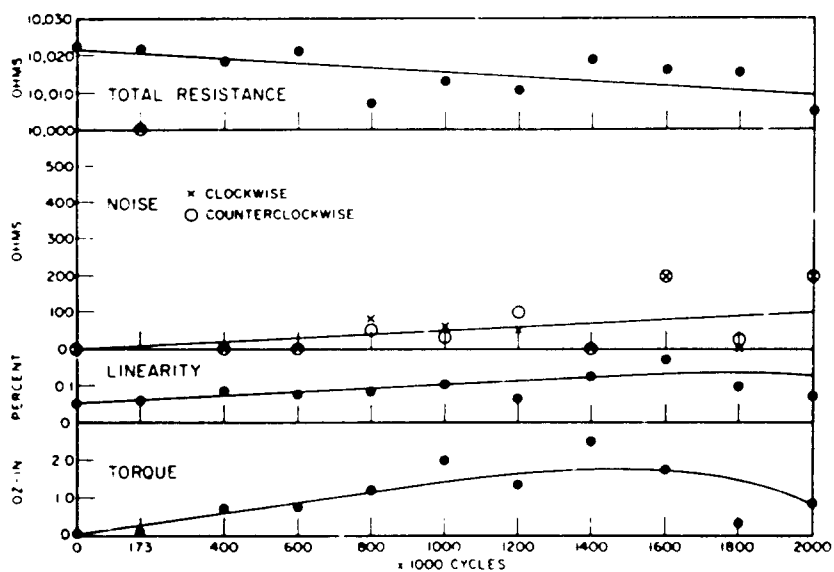Fig. 7 - Life test characteristics of Source 2, 2C potentiometer

Fig. 8 - Life test characteristics of Source 3, 3C potentiometer

At the beginning of the life tests, all the potentiometers exhibited zero noise level.
By the time 173,000 cycles of operation had been reached, the noise of three potentiometers
(1D, 1E, 3C) had exceeded the maximum limit of 100 ohms. Considerable scattering of the
data exists. Examination of typical noise data in Figs. 5 through 9 shows a trend toward
increasing noise. This was true in general of all the potentiometers and may be an indi-
cation of gradual depletion of lubricant from contact areas (5). In certain instances the
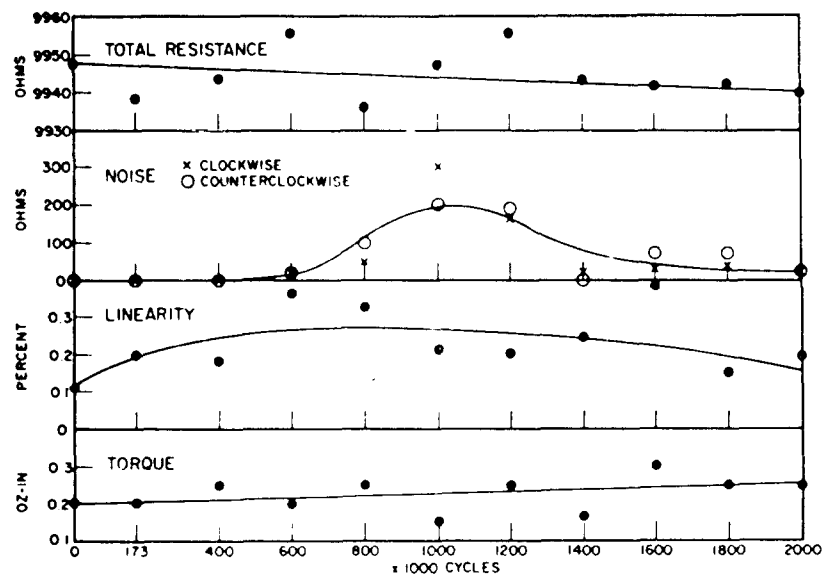
Fig. 9 - Life test characteristics of Source 4, 4C potentiometer

noise level began to decline as the end of the test was approached. By the time 2,000,000
cycles of operation had been reached, the noise level of three potentiometers (1A, 4A, 4C)
had fallen to less than 100 ohms, and of these, one (4A) had a zero noise level. This
phenomenon has also been observed by others (5). This behavior could be attributed to a
"wearing in" of the contact arm and windings so that better metal-to-metal contact resulted.
The Source 1 potentiometers with the precious-metal windings (1A, 1B, 1C) and those made
by Source 2 with the improved-proces· windings (2A, 2B, 2C) were superior to the other
potentiometers from the standpoint of noise characteristics according to the Ford report (1).

The torque required to operate a potentiometer is a function of the friction between the
contact arm and winding, between slip ring and brushes, and in the bearings. The maximum
torque permitted in the Ford tests was 1 oz-in.

Wear between wiper and winding contact surfaces can cause either an increase or a
decrease in torque depending on whether the wear results in roughening of contact sur-
faces or whether a smoothing action, particularly on the winding, predominates. Reducing
the unit load on the windings by an increase in contact area due to wear or a reduction of
contact arm tension caused by wear could reduce the torque requirements.

Study of the data tabulated in the Ford report (1) shows that the torque requirements
of two Source 3 potentiometers, 3B and 3C, exceeded the maximum of 1 oz-in. permitted.
These were the two units which contained locked bearings. On the other hand, the torque
required to operate the small Source 2 units remained at 0.01 oz-in. throughout most of
the life test. However, in most cases, typified by the torque curves shown in Figs. 5
through 9, the torque tended to increase. In only one or two instances did it appear to
decline near the end of the test.

RELATIONSHIP OF WEAR TO POTENTIOMETER CHARACTERISTICS

Although very little information has been made available concerning the composition
of metals and lubricants used in the potentiometers, it has been possible to estimate the
overall significance of wear in certain parts of the units.

Wear of the slip-ring and brush assemblies was rather insignificant (except in the Source 4 potentiometers) and probably contributed very little to changes in total resistance, linearity, noise, or torque. It was evident that the greatest amount of wear had occurred on the contact arms and to a lesser extent on the windings.

In order to determine if any relationship exists between contact-arm wear and change in total resistance, linearity, or noise, graphs were prepared. These compare the magnitude and direction of the changes which have occurred in the above properties with the size of the contact-arm-wear scars at the completion of the life tests.

When the changes in total resistance of 14 of the potentiometers are plotted against the size of the wear scars (Fig. 10), the data are widely scattered and no relationship exists. The figure does show that in all but two cases the total resistance had decreased by the time the tests had ended.
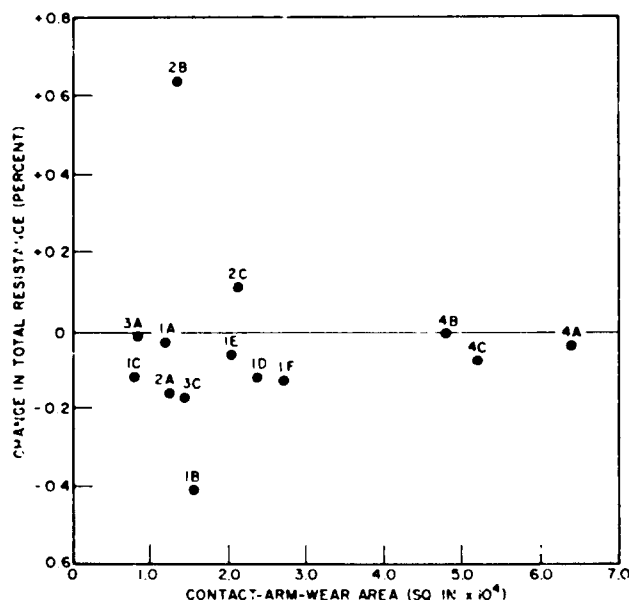

Fig. 10 - Percent change in total resistance
versus contact-arm-wear area

The percent change in departure from linearity of the same 14 potentiometers is plotted against the size of the contact-arm-wear scar in Fig. 11. For small wear scars there is no correlation, but increased deviation is evident as the scars become large.

Data on the 15th potentiometer, Source 3 (3B), were not included in either Fig. 10 or Fig. 11 because of the magnitude of the changes which occurred by the time the tests had ended. This potentiometer exhibited both a very severe loss in total resistance (45%) and a large increase in departure from linearity (428%).

When the magnitude of the noise is plotted against the contact-arm-wear scar areas of all the potentiometers (Fig. 12) at the end of the life tests, some degree of correlation appears to exist. Only the Source 4 (4B) and Source 1 (1A) data are widely scattered. This
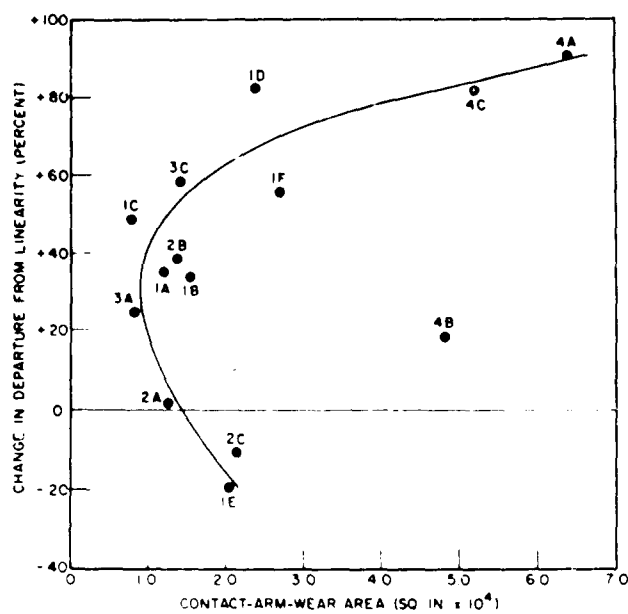
Fig. 11 - Percent change in departure from
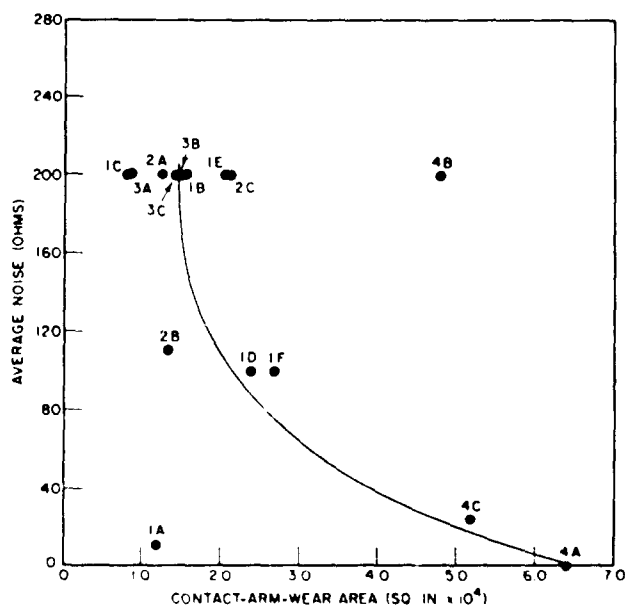linearity versus contact-arm-wear area

Fig. 12 - Average noise versus
contact-arm-wear area

correlation would seem to indicate that some wearing of the contact point is desirable if noise is going to be maintained at a low level for long periods of operation. Other investigators (6) have indicated that wear appears to be important in controlling noise. If the greatest source of noise is the presence of surface films on the contact areas as is contended by some (5), then sufficient wear to remove these films would be desirable. However, it must be pointed out that the noise level was zero for all the potentiometers at the beginning of the tests before any wear had occurred. At this time no wear products had been generated which could come in between the wiper and winding and interfere with good metal-to-metal contact. It should also be recalled that it was the Source 1 potentiometers with the precious-metal windings (1A,1B,1C) which sustained the least average wiper wear and operated the longest period before exceeding the 100-ohm noise limit.

DISCUSSION OF A NEW TECHNIQUE FOR LUBRICATING POTENTIOMETERS

As was pointed out earlier, all the potentiometers exhibited zero noise output at the beginning of the life tests. As the tests progressed, noise levels rose, though considerable variation was evident. Noise in potentiometers may arise from several sources. These include the triboelectric effect, caused by friction from the abrasive action of the sliding contact on the resistance wire; thermoelectric effect, caused by temperature differences at conductor junctions; contact-potential effects, which arise when dissimilar metals come in contact; and chemico-electric effects arising from chemical contamination of the contact surfaces.

The increase in noise during the service life of a potentiometer reflects increased variability of the contact resistance. This may be caused by the presence of wear products, deterioration of lubricants, or the deposition of poorly conducting films between the metallic contacting surfaces. Improvement of performance has been attained through the use of noble or precious metals, partially because these metals resist oxidation and sulfide formation. Many of the factors which cause potentiometer noise and those steps which can be taken to minimize noise have been investigated by others (1,4,5,6,7,8).

Regardless of the specific causes of electrical noise in potentiometers, the rise in noise output during service would seem to be associated with a gradual depletion of the lubricant from the contacting surfaces. It has been noted (5,6) that replenishing the lubricant with a fresh supply causes a lowering of the noise output. The fresh lubricant may wash out wear products or dissolve poorly conducting films from the contact surfaces and thereby re-establish metal-to-metal contact. The presence of the new lubricant may also reduce friction and abrasion. Many of the contact cleaners on the commercial market operate on one or more of these principles. However, the inaccessibility of many potentiometers in computer systems makes relubrication or cleaning of these units impractical.

If depletion of the lubricant is an important factor in causing a rise in noise in potentiometers, it would follow that if loss of the lubricant could be prevented improved noise characteristics would be expected. From the standpoint of retention of the lubricant, the use of grease would seem to be desirable. However, if the oil portion of the grease evaporates or creeps away during storage or during prolonged use of the potentiometer, the soap concentration of the grease becomes quite high. This frequently results in the agglomeration of dry soap particles. If these particles become lodged between contacting surfaces, the contact resistance changes and the potentiometer becomes noisy. This condition has been observed by other investigators (5,6).

Some investigators feel that oil is to be preferred as a potentiometer lubricant, though it is admitted that many oils, particularly the silicones, are notoriously susceptible to creeping over surfaces (5,6). Since many synthetic-type lubricants now available have very low volatility, loss of these materials from critical areas in a potentiometer during service would be primarily through migration or creeping. This suggests that control of oil spreading could be a major factor in extending potentiometer life.

It has been found that thin coatings of certain nonwettable fluorochemical compounds are effective in blocking the creep of oils of various origins over a variety of surfaces (9,10). One of these materials made by the Minnesota Mining and Manufacturing Company and designated as FX 706 has been used very successfully in the prevention of oil loss from instrument bearings (11). It has been found that this method can also be used to control oil loss in potentiometers.

In order to demonstrate the effectiveness of FX 706 in preventing the migration of lubricant from the critical contact areas in potentiometers, it was applied to two of those of Source 4 origin. Potentiometers 4A, 4B, and 4C, which had been lubricated previously with oil, were washed in benzene and dried. The fluorochemical FX 706 was applied to the interior surfaces of the cases adjacent to the resistance windings and around the contact areas of the contact arms of units 4A and 4B. Potentiometer 4C was not treated. A low-surface-tension oil consisting of a blend of a silicone oil and a diester was applied in generous quantities to the contact surfaces of all three potentiometers. Examination of potentiometers 4A and 4B proved that the lubricant did not spread beyond the barrier coating formed by the FX 706 material, regardless of the orientation of the potentiometers. However, the lubricant which had been placed on the contact areas of the untreated 4C potentiometer began to spread onto the interior surface of the case in less than an hour.

This experiment proved that it is possible to prevent the migration of oil from strategic locations in potentiometers. The presence of a generous supply of liquid lubricant on the resistance winding at all times should be conducive to "floating" away wear products and other interfering media as they are formed on the contacting surfaces. The coatings would also ensure a copious supply of lubricant to prevent abrasion and to reduce friction. It would be expected that the effective retention of the lubricant would greatly extend storage life and reliability.

If a grease is preferred as a potentiometer lubricant, the barrier coating would prevent the loss of the oil phase, the composition of the grease would remain unchanged and it would not dry out. Whichever type of lubricant is used, the coatings would make sure that a plentiful supply of lubricant would be available for an extended time at the point where it is needed. This should be conducive to low noise output and less contact wear and should alleviate the need for replenishing the lubricant in order to control noise.

One beneficial side effect of the use of the barrier-coating system in potentiometers is the reduction of surface electrical leakage (10). Conductivity across the surface of these barriers is extremely low because these materials have low adhesion for dust, oil, grease, and water and fortunately are not removed by most nonfluorinated solvents. The coatings should be especially valuable for use in electronic equipment subject to operation in a high-humidity environment.

It was noted that most of the potentiometer ball bearings examined had been given a very small amount of lubricant. This tends to promote the fretting corrosion noted in several instances. The limitation of the quantity of lubricant, particularly when oils are used, is usually necessary to prevent the liquid from creeping out and contaminating areas adjacent to the bearings. Since conclusive tests (11) have shown the barrier coatings to be very effective in holding generous quantities of lubricant in ball bearings, application of this system to potentiometer bearings would do much to prevent the deterioration observed.

SUMM.¡RY AND CONCLUSIONS

It is evident that proper evaluation and interpretation of the wear phenomena encoun-
tered in the Ford Instrument Company tests of the 15 potentiometers is limited by the la‍ck
of pertinent information concerning potentiometer materials of construction and lubricant
compositions. However, it was possible to make general observations that may be of
significance.

Except for those in the Source 4 potentiometers, collector rings and brushes showed
little wear and did not appear to be sources of trouble, provided they were well lubricated
and were properly tensioned. Wear on the windings was not severe. The greatest wear
occurred on the contact arms or wipers. Those in the Source 4 potentiometers exhibited
by far the most, while those of Source 1 manufacture with precious-metal windings sus-
tained the least wear.

The contact arms and windings of the Source 1 potentiometers had been lubricated
with oiL Greases had been used for this purpose in all the other units and on all collector
rings and brushes. The lubricant in the Source 2 potentiometers had solidified.

Approximately half the ball bearings were rough in operation, and two had become
locked because of the presence of reddish-brown fretting corrosion products in the bearings.
These bearings were loose on the shafts.

Both oils and greases had been used as lubricants in the ball bearings. In most cases,
the quantity of lubricant was small. Silicone gel was found in the Source 2 bearings, one
indication of the inadvisability of using the silicones as lubricants for this purpose. In
many instances, balls and races were covered with dark brown films.

Exan.¡nation of the life-test data revealed that the total resistance of all but one of
the potentiometers changed less than 2% and that the tendency was toward a decrease in
resistance as the tests progressed. Because of the opposing effects of winding wear and
deposition of wear debris between coil turns, it is obvious that changes in total resistance
cannot be used as a criterion of winding wear.

Changes in linearity characteristics of potentiometers during use are caused by some
of the same factors involved in changes in total resistance. An operating potentiometer
is rarely used uniformly over the entire length of the resistance coil; thus, the resistance
becomes nonlinear both because of localized reduction in conductor cross section and
because of nonuniform deposition of wear products. Only the Source 1 potentiometers with
the precious-metal windings passed the linearity requirements at the conclusion of the
tests.

All the potentiometers exhibited zero noise output at the beginning of the tests, but
noise levels rose as the tests progressed. In certain cases, the noise decreased near the
end of the tests. The Source 1 potentiometers with the precious-metal windings and the
Source 2 units with the improved process windings were superior from the standpoint of
noise characteristics.

The torque required to operate the small Source 2 potentiometers remained unchanged
at a very low level throughout the tests. Most other units exhibited an increase in torque
as the tests progressed. Only those potentiometers which contained locked bearings
exceeded the torque requirements.

The size of the wear scar areas on the contact arms did not appear to have any simple
relationship to changes in total resistance or torque requirements. However, there was

some indication that the deviation from linearity increased as the wear scars became larger. If data could have been obtained at intervals during the course of the tests, perhaps more significant relationships would have been evident.

When contact-arm-wear area was compared with noise level at the conclusion of the tests, it was found that in general potentiometers with arms having the greatest wear produced the least noise. This would indicate that some wear may be conducive to lower noise level. Comparisons of this nature during the course of the tests would have been very informative.

It is concluded that the principal source of noise in potentiometers is at the point of contact between the wipers and the resistance windings. It may arise from a variety of causes and it is greatly influenced by the type of winding materials used and by the nature of the wiper lubricant. Oil is preferred as a potentiometer lubricant by some manufacturers, though the use of greases has an advantage from the standpoint of retention.

It is believed that the increase in noise of potentiometers during storage or in service may be a function of the loss of lubricant from vital areas by migration or creep, particularly if oil is used. Loss of the oil phase in a grease lubricant may result in a rise in soap concentration leading to hardening of the materials with a consequent increase in noise level.

The use of nonwettable fluorochemical barrier films to prevent the creeping of oil is suggested as an effective means of preventing the loss of lubricant from critical points. This method has met with much success in preventing the loss of lubricants from instrument bearings. The resistance of this material to wetting by water would help to prevent surface electrical leakage under conditions of high humidity.

It is obvious that insufficient attention has been directed to the selection and lubrication of ball bearings for these potentiometers. More generous application of lubricant held in the bearings by the barrier coatings would likely have prevented most of the adverse bearing conditions noted.

Potentiometers having precious-metal windings gave superior performance. In view of the higher cost of potentiometers using precious metals, it would be desirable to determine if new lubricants could be developed which would permit the use of less expensive metals. Such an undertaking would be greatly aided by the application of the barrier-coating system to control loss of the lubricants by migration.

RECOMMENDATIONS

    1. It is recommended that studies be undertaken which would lead to the identification and development of lubricants capable of providing better potentiometer performance than that afforded by the lubricants now in use.

    2. Further studies by the manufacturers should be made of the practicability of applying the barrier-film technique to control the migration of lubricants from the contact areas of precision potentiometers.

    3. More attention should be directed toward the selection and proper fitting of ball bearings for potentiometers.

    4. It is recommended that silicone lubricants not be used in potentiometer ball bearings.

    5. Fluorochemical barrier films should be applied to potentiometer bearings to prevent loss of lubricant during storage and use.

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